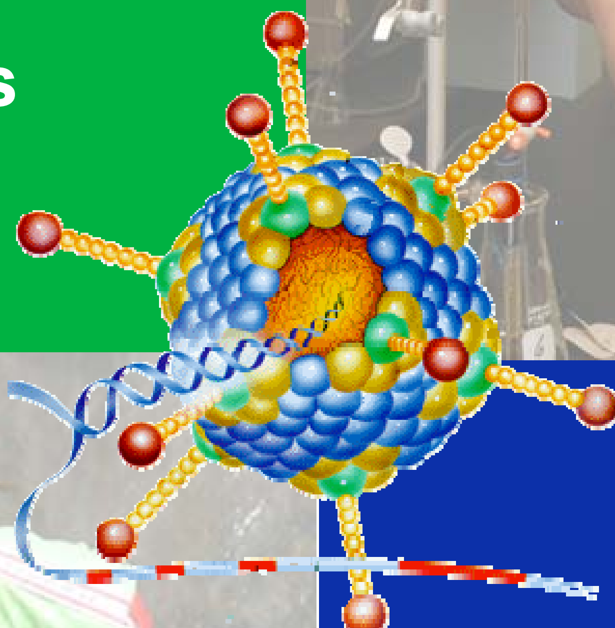
Refraction and Reflection

Teacher's Guide



The waterCAMPWS
Center for Advanced Materials
for Purification of Water with Systems

Curriculum Connection: Physics

Bloom's Taxonomy:

Grade Level: 9-12

Topic: Refraction, Reflection, Index of Refraction and the Critical Angle

Lesson Duration: Approximately 1.5-2 hours

Purpose

This W.E.T. is centered around principles of refraction and reflection of electromagnetic waves. Water treatment plants often use the turbidity of water to determine what kinds of contaminants are in the water and they also use specific spectrums of light to disinfect water as well.
Using trigonometric identities and Snell's Law students identify the index of refraction of various solutions. Once students calculate the index of refraction of water and vinegar respectively they can find a range of values in which an unknown index of refraction resides.

Learning Goals and Objectives

1. Students will learn key vocabulary associated with refraction and reflection and Snell's Law.
2. Have a basic understanding of refraction, reflection, and be able to apply Snell's Law to know and unknown substances.
3. Determine index of refraction of various solutions
4. Recognize the passage of refracted beams though different medium
5. Understand the concept of Snell's Law
6. Understand how the speed of electromagnetic waves in different matters are related
7. Determine the critical angle for total internal reflection
8. Calculate the index of refraction of water and vinegar respectively.
9. Understand how refraction and reflection are used in water purification techniques.

Benchmarks and Standards

Illinois State Learning Standards:

- *12.B.4a* Compare physical, ecological and behavioral factors that influence interactions and interdependence of organisms.
- *12.C.3a* Explain interactions of energy with matter including changes of state and con¬servation of mass and energy.
- *12.C.3b* Model and describe the chemical and physical characteristics of matter (e.g., atoms, molecules, elements, compounds, mixtures).
- *12.D.3a* Explain and demonstrate how forces affect motion (e.g., action/reaction, equilibrium conditions, free-falling objects).
- *12.D.4a* Explain and predict motions in inertial and accelerated frames of reference.
- *12.D.4b* Describe the effects of electromagnetic and nuclear forces including atomic and molecular bonding, capacitance and nuclear reactions.

- *13.A.4a* Estimate and suggest ways to reduce the degree of risk involved in science activities.
- *13.A.4b* Assess the validity of scientific data by analyzing the results, sample set, sample size, similar previous experimentation, possible misrepresentation of data presented and potential sources of error.
- *13.A.5b* Explain criteria that scientists use to evaluate the validity of scientific claims and theories.
- *13.A.3c* Explain what is similar and different about observational and experimental investigations.

NSES Standards: In grades 9-12, students will learn:

- *Content A* Abilities necessary to do scientific inquiry & understandings about scientific inquiry.
- *Content B* Structure and properties of matter, motions and forces, and interactions of energy and matter
- *Content E* Abilities of technical design and understandings about science and technology
- *Content F* Personal and Community health, population growth, natural resources, environmental quality, natural and human induced hazards, and science and technology in local, national and global challenges
- *Teaching A* Plan an inquiry-based science program for their students
- *Teaching B* Guide and facilitate learning
- *Teaching D* Design and manage learning environments that provide students with the time, space and resources need for learning science.
- *Teaching E* Develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

Materials and Equipment

Materials required for this lesson are (for each group of students):

- 5 50 cm Plexiglas Tank
- Beaker stand
- Test tube clench
- Laser pen
- Meter ruler
- Angle ruler
- 1500 ml Water
- 1500 ml Vegetable oil
- 1500 ml Vinegar
- Tape or chalk

Introduction

Objects that are in water, or even off far in the distance, can sometimes look strange. A straw in a glass of water sometimes look as if it's bent, or as if part of the straw that is in the air is floating a few centimeters off from the part in the water. Why does this occur?

Light travels through empty space at a speed of about 300 million m/s. Light passing through a material such as air, water, or glass, however, travels more slowly than this, because the atoms that make up the material interact with the light waves and slow them down. Compare the speed of light through the different materials in figure 1.

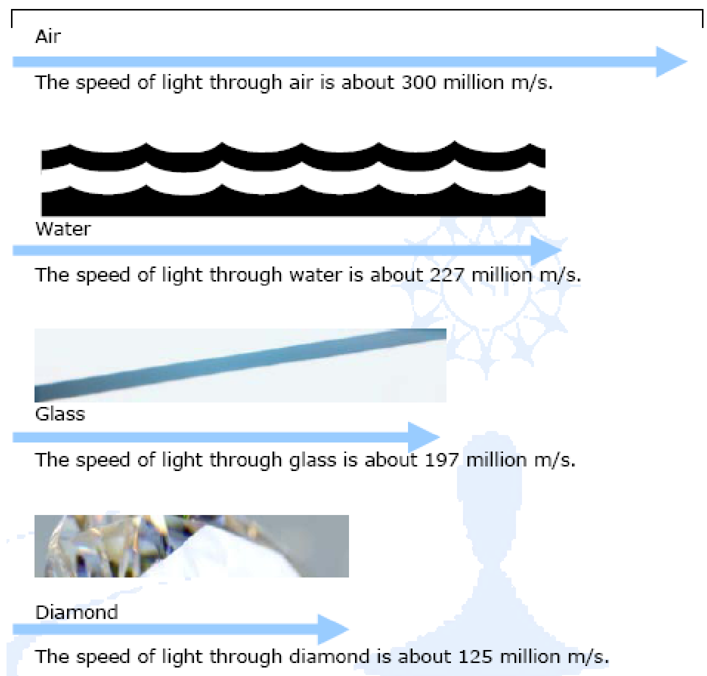


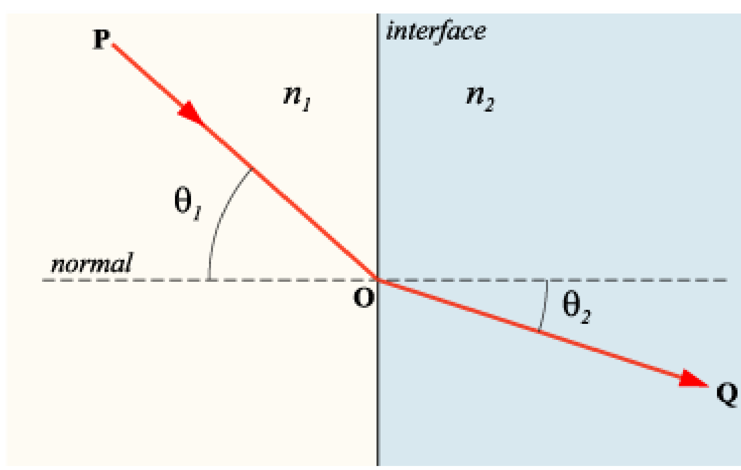
Figure 1.

Light rays from the part of the straw that is under water travel through the water, glass, and then the air before they reach your eye. The speed of light is different in each of these mediums. If the wave is traveling at an angle to the boundary between the two media, it changes directions, or bends. This bending is called **refraction**. This bending is due to the change in speed the light wave undergoes as it moves from one medium into the other. The greater the change in speed is, the more the light wave bends, or refracts.

Snell's Law

Snell's law is the simple formula used to calculate the refraction of light when travelling between two media of differing refractive index. It is named after one of its discoverers, Dutch mathematician Willebrord van Roijen Snell.

In the diagram on the right, two media of refractive indices n1 (on the left) and n2 (on the right) meet at a surface or interface (vertical line). n2 > n1, and light has a slower phase velocity within the second medium.



A light ray PO in the leftmost medium strikes the interface at the point O. From point O, we project a straight line at right angles to the line of the

interface; this is known as the normal to the surface (horizontal line). The angle between the normal and the light ray PO is known as the angle of incidence, θ1. The ray continues through the interface into the medium on the right; this is shown as the ray OQ. The angle it makes to the normal is known as the angle of refraction, θ2. Snell's law gives the relation between the angles θ1 and θ2:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

Note that, for the case of θ1 = 0° (i.e., a ray perpendicular to the interface) the solution is θ2 = 0° regardless of the values of n1 and n2. In other words, a ray entering a medium perpendicular to the surface is never bent.

The above is also valid for light going from a dense to a less dense medium; the symmetry of Snell's law shows that the same ray paths are applicable in opposite direction.

A qualitative rule for determining the direction of refraction is that the ray in the denser medium is always closer to the normal. A handy way to remember this is to visualize the ray as a car crossing the boundary between asphalt (the less dense medium) and mud (the denser medium). Depending on the angle, either the left wheel or the right wheel of the car will cross into the new medium first, causing the car to swerve.

Snell's law is only generally true for isotropic media (such as glass). In anisotropic media such as some crystals, birefringence may split the refracted ray into two rays, the ordinary or o-ray which follows Snell's law, and the other extraordinary or e-ray which may not be co-planar with the incident ray.

In geometric optics, at a refractive boundary, the critical angle is the angle of incidence above which total internal reflection occurs.

The angle of incidence is measured with respect to the normal at the refractive boundary. It is given by:

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right),$$

where θc is the critical angle, n2 is the refractive index of the less dense medium, and n1 is the refractive index of the denser medium. This equation is a simple application of Snell's law where the angle of refraction = 90°.

Note: Total internal reflection occurs only when the incident ray is in the denser medium.

If the incident ray is precisely at the critical angle, the refracted ray is tangent to the boundary at the point of incidence.

For visible light travelling from glass into air (or vacuum), the critical angle is approximately 41.5°.

Source: Wikipedia.org

Total internal reflection

When moving from a dense to a less dense medium (i.e. n1 > n2), it is easily verified that the above equation has no solution when θ1 exceeds a value known as the critical angle:

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

When θ1 > θcrit, no refracted ray appears, and the incident ray undergoes total internal reflection from the interface.

Activities

1. Present the introduction to this lab, or some other materials appropriate to properties of water, specifically reflection, refraction and Snell's Law.
2. Break the students into groups of 2-4 and distribute the materials for the lab.
3. Give students approximately 45-50 minutes to follow the procedures listed in their lab books.
4. Have students complete the comprehension and analysis questions in their lab books.
5. Conclude the lab with a discussion of their results.

Conclusion

Have the students clean up the lab. With remaining time, have some of the groups share their results. Collect the lab books at the end.

Assessment

The lab book should provide an assessment tool for this lesson.